Yonago Acta medica 2009;52:77–84

Indoor Air Quality of Tottori University Lecture Rooms and Measures for Decreasing Carbon Dioxide Concentrations

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To make clear the realities of indoor air (IA) pollution in lecture rooms of Tottori University in Japan, we studied air quality by monitoring the CO_2 level, an index of IA pollution. We changed IA environment of lecture rooms while the lecture was given by using fan-ventilation or not, and with room doors open or closed: we monitored the CO_2 level at 5-min intervals during 2 or 3 consecutive 90-min lectures using an infrared ray absorption type CO_2 monitor. Based on the observed levels for 90 min, we calculated the ventilation rate (times of operating the ventilation fan), and estimated CO_2 level change in ventilated and non-ventilated rooms for a 90-min lecture with the ventilation rate. In non-ventilated rooms, the observed and estimated CO_2 level exceeded the maximum of 1,500 ppm specified by the Japanese Government. The excess was irrespective of the ratio of air volume/person in non-ventilated rooms with doors closed. During the 1-h lunch break with doors open, over 5,000 ppm levels dropped below the standard. During the lecture in fan-ventilation, the CO_2 level was decreased to below or near above the standard. Fan-ventilation during the lecture break reduced the level nearly to that in the outside air. In the case of no fan-ventilation during the following lecture(s), the level exceeded the standard. To maintain a clean air environment in highly airtight university lecture rooms, ventilation during lectures was crucial, which can be done effectively by the use of ventilation fans. Use of the estimated level is generally adaptive in promoting the use of ventilation fans.

Key words: air quality; carbon dioxide; school environmental health; ventilation

Cause of the sick building syndrome are mainly linked with the trend of making highly insulated airtight houses, which lowers the amount of natural ventilation (Iwashita et al., 1997). As other causes, generations of volatile organic compounds and formaldehyde were reported (Hays et al., 1995). The key index of indoor air (IA) pollution is the CO_2 concentration. If the indoor CO_2 level is high, the risk of the sick building syndrome rises (Gupta et al., 2007). The degree of contamination of IA quality can be evaluated by measuring CO_2 levels. Appropriate room ventilation is necessary to maintain an appropriate environment for IA or to decrease the level of toxic chemical substances.

In many elementary schools, window frames in classroom doors and walls facing the hallway are made of wood and poorly fitted, so that elementary schools have no airtight rooms, and generally use natural ventilation. In contrast, university lecture rooms with highly airtight steel-made doors are equipped with ventilation fans and depend on artificial ventilation. In Japan, however, we have no

Abbreviation: IA, indoor air

Table 1. Characteristics and usage of monitored rooms with CO_2 levels at monitoring start

		Room X		Room Y	
Room volume	(m^3)	224		216	
Seating capacity		48		81	
Ventilation fan		Not operated	Operated	Not operated	Operated
CO_2 at monitoring start	(ppm)	408	437	497	471
Ventilation rate	(times/h)	1.0	7.0	0.7	5.0
Number of people in the room					
Period 2				64 [3.4]	59 [3.7]
Period 3				60 [3.6]	60 [3.6]
Period 4		24 [9.3]	25 [9.0]	55 [3.9]	60 [3.6]
Period 5		24 [9.3]	25 [9.0]	52 [4.2]	55 [3.9]
Monitored day (2007)		12 Dec.	19 Dec.	14 Dec.	21 Dec.

[ ], ratio of air volume/person in m^3/h/person.

standardized regulation in fan-ventilating: ventilation is not especially recommended, and the operation is left up to room users. The frequency of IA pollution increases in summer and winter, because of the above-noted few ventilation times partly to save energy and to maintain air-conditioned effects. In addition, the IA pollution occurs more easily in school than in office because of the population density (Clements-Croome et al., 2008). Because no major problems arise as a result of ignoring air quality, this tends to be forgotten as an important aspect of school life (Griffiths and Eftekhari, 2008). The air quality has been studied on elementary schools and residential houses (Shaughnessy et al., 2006; Kinshella et al., 2001), but little on university lecture rooms, due to the difference in ventilation methods and air volume. From the viewpoint of study and health for university students, we investigated IA pollution in Tottori University lecture rooms by measuring CO_2 levels continuously, and discussed possible countermeasures to deal with observed problems.

Materials and Methods

Measurement sites

CO_2 levels in non-ventilation were monitored in Periods 4 and 5 on 12 Dec. 2007 in Room X (Tottori University Faculty of Agriculture) and from Periods 2 to 5 on 14 Dec. 2007 in Room Y (Tottori University Faculty of Engineering). We chosen Rooms X and Y, because the rooms were consecutively used for 2 periods or longer at that time of the year, because the rooms could hold students to the rooms' full capacity and because the rooms were newly installed with total heat exchange type ventilation fans after rebuilding in 2003. CO_2 levels in ventilation were monitored in the same rooms at the same Periods 1 week later.

The volume and seating capacity of lecture rooms are described in Table 1. The openness or closeness of room doors and fan-ventilating or not on the monitored days were also recorded. Indoor and outdoor temperatures were continuously measured with a temperature humidity data logger (TH-101, Micro Techno, Kawasaki, Japan). The indoor temperature was measured at the same sites as the CO_2 level was monitored, and the outdoor temperature, on the outside stairs on the 2nd floor of the Faculty of Regional Sciences building.

CO_2 level monitoring

An infrared absorption type CO_2 monitor (Telaire 7001, Onset Computer, Pocasset, MA) (measuring range: 0–10,000 ppm, accuracy: ± 50 ppm) was set up at desk-top height in the center of each room, and the CO_2 level was continuously monitored at intervals of 5 min throughout the period. CO_2 levels in the rooms before the monitoring start had been raised because of the previous lecture use, and so we started monitoring after CO_2 levels fell to about 450 ppm. Following the monitoring in the lecture time, we continued monitoring until 9:00 AM on the next day, and attenuated CO_2 levels were used to calculate the ventilation rate (times of operating the ventilation fan) in after-school sealed rooms.

Calculation of the ventilation rate

The ventilation rate when the rooms were sealed was calculated with the CO_2 data observed from the lecture end to 9:00 AM on the next day, using the formulae *(1)* and *(2)* noted below (Pharmaceutical Society of Japan, 2000): the ventilation rate when the rooms were fan-ventilated, using the formulae *(2)* and *(3)* (Pharmaceutical Society of Japan, 2000). The ventilation fan we used in each room was the total heat exchange ventilator with the air amount set to low to avoid the running noise. The running noise was measured with a Sound Level Meter NA-20 (Rion, Tokyo, Japan) at 30-min intervals for 5 min. The students were given lectures on general education. Most were seated at the beginning of the lectures and sat quietly during class. The number of people in a room was not changed excepting a few latecomers and those who left early. We assumed the number of people in the room or metabolic rate not changed, and analyzed the CO_2 level generated by students themselves, with reference to the "Standards for School Environmental Sanitation" (0.022 m^3/h) (Ministry of Education, Culture, Sports, Science and Technology of Japan, 2004).

$$V = 2.303 \times \frac{V_R}{t} \times \log\frac{C_1 - C_0}{C_t - C_0} \quad \cdots\cdots\cdots\cdots (1)$$

$$E = \frac{V}{V_R} \quad \cdots\cdots\cdots\cdots (2)$$

$$V = \frac{M \times 100}{C_t - C_0} \quad \cdots\cdots\cdots\cdots (3)$$

$$V_t = V_R \times t \times E \quad \cdots\cdots\cdots\cdots (4)$$

$$C_t = C_0 + (1 - e^{-Et})\frac{M \times 100}{V_t} \quad \cdots\cdots\cdots\cdots (5)$$

where C_0, CO_2 level of air entering from outside (%); C_1, CO_2 level of IA at a monitoring start (t = 0) (%); C_t, average CO_2 level of IA after time t (%); E, ventilation rate (times/h); M, amount of CO_2 generated indoors (m^3/h); t, elapsed time between a monitoring start and the next start (h); V, amount of ventilation (m^3/h); V_R, room volume (m^3); V_t, total amount of ventilation for time t (m^3).

Estimation of CO_2 levels

To make clear the CO_2 level change during a lecture over 90 min, we calculated the estimated levels with the formulae *(4)* and *(5)* (Pharmaceutical Society of Japan, 2000), at 5-min intervals according to the ventilation rate in ventilated or non-ventilated rooms.

Results

Table 1 shows fan-ventilating conditions, CO_2 levels, number of people in the room and ratio of air volume/person classified by room.

Usage of Room X on monitored days

Figure 1-I shows the schema of Room X, where we monitored during Periods 4 and 5. The lecture on monitored days took 2 full periods, and no students entered or left as the lecture went on: breaks between lectures were different from the usual. On 12 Dec. when Room X was not ventilated, the lecture break was from 16:35 to 16:45: this class was a laboratory class, and doors were often opened and closed. On 19 Dec. when Room X was ventilated, the lecture ended at 16:40 without break.

Level change in Room X

Figure 2 shows changes in non-ventilated Room X (12 Dec.) and ventilated Room X (19 Dec.). This figure also shows openness or closeness of room doors, and ventilation or non-ventilation in doorway areas. Indoor CO_2 levels at the monitoring

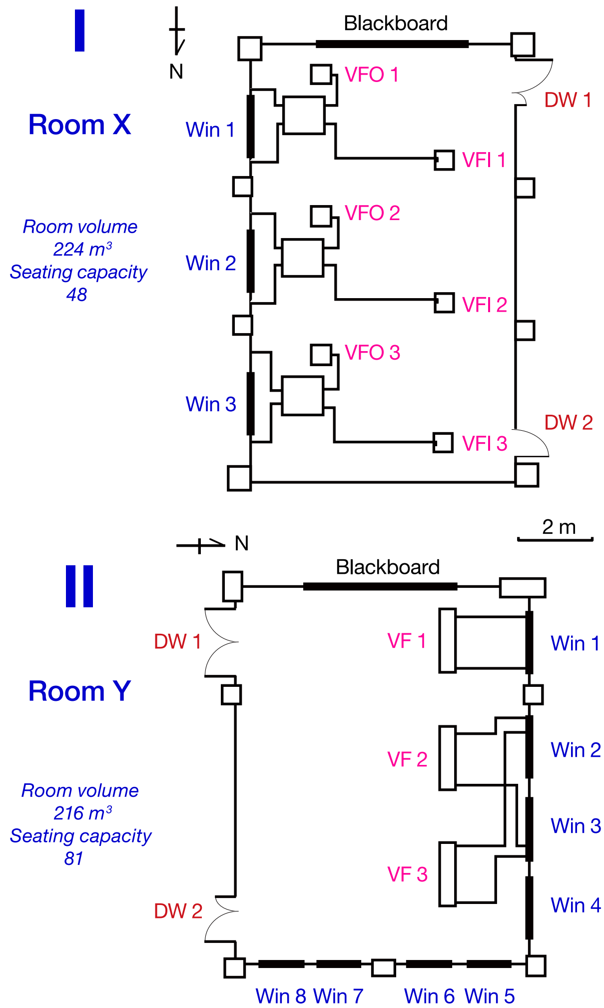

Fig. 1. Schemas of lecture rooms. **I:** Faculty of Agriculture Room X. **II:** Faculty of Engineering Room Y. DW, doorway; VF, ventilation fan; VFI, VF inlet; VFO, VF outlet; Win, window.

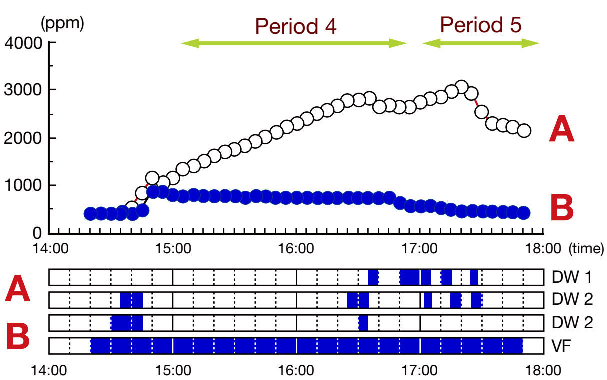

Fig. 2. Changes in CO_2 levels monitored in Room X. **A:** not fan-ventilated. **B:** fan-ventilated. ■: fan-ventilated with doors open. DW, doorway; VF, ventilation fan.

start were 408 ppm on 12 Dec. and 437 ppm on 19 Dec. (Table 1). On 12 Dec., the CO_2 level in non-ventilated Room X began to rise from the lecture start (14:40), exceeded 1,500 ppm at 15:15 and continued to rise. It dropped slightly during the break (16:35–16:45), but rose to 3,070 ppm at 17:20 when the laboratory class began. Thereafter, the level decreased in doorway areas as students frequently entered or left. At 17:50 when the class ended on 12 Dec., the level was 2,154 ppm and the outdoor CO_2 level was 398 ppm. On 19 Dec., the CO_2 level in ventilated Room X rose from the lecture start (14:40), and reached 883 ppm 10 min later. By the lecture end (16:45), the level had increased by 750 ppm but did not exceed 1,500 ppm. The outdoor CO_2 level on 19 Dec. was 403 ppm. The ventilation rate was 1.0 time/h for after-school sealed Room X and 7.0 times/h for ventilated Room X (Table 2).

Usage of Room Y on monitored days

Figure 1-II is the schema of Room Y. During Periods 2 to 5, CO_2 levels were monitored in non-ventilation on 14 Dec. and in ventilation on 21 Dec. There were about 60 people on both days (Table 1). During the lunch break, 4 to 20 people seated between 12:00 and 12:40, and about 20 to 60 people between 12:40 and 13:00.

Level change in Room Y

Figure 3 shows changes in Room Y on 14 Dec. when the room was not ventilated and on 21 Dec. when it was ventilated. Figure 3 also shows changes when the doors were open or closed, with ventilation or non-ventilation in doorway areas. The indoor level in non-ventilated Room Y was 497 ppm at 10:05 when the monitoring was started (Table 1). The students enterd the room immediately after the monitoring start. At 10:30, the level exceeded 1,500 ppm, and at 11:50 (end of Period 2) reached 5,248 ppm. During the lunch break (11:50–13:00), Doorways 1 and 2 were opened, and the level was quickly dropped to 1,144 ppm. At 13:00, Period 3 began and the level rose again, and at 14:30 (end of Period 3) reached 5,036 ppm. Between 14:30 and 14:40 (break between Periods 3 and 4), Doorways 1 and 2 were opened. Till 14:50 Doorway 2 remained open even after the start of Period 4, and the level decreased to 3,273 ppm. However, once Doorway 2 was closed, at 16:05 (end of Period 4) it rose again to 5,312 ppm. Between 16:20 and 16:30, after Period 5 began, Window 2 was 25% open, and the level rise was slowed. Once Window 2 was closed, the level increase became more rapid, and at 17:40 (end of Period 5) reached 6,276 ppm. Between 17:40 and 17:55 (end of monitoring), Doorways 1 and 2 were intentionally opened, and the level was decreased to 2,601 ppm.

The indoor level in ventilated Room Y was 471 ppm at 10:05 when the monitoring was started (Table 1). From 10:15, the level began to rise as the number of people in Room Y increased, and at 10:40 reached 1,653 ppm. By 11:50, the level changed to about 1,600 ppm (end of Period 2). During the lunch break, Doorways 1 and 2 were opened, and the level dropped to 1,100 ppm. At 13:00 (start of Period 3), Doorways 1 and 2 were closed, and by 14:25 the level reached 1700 ppm (end of Period 3). From 14:40 (start of Period 4), Doorway 2 was open, and the level was decreased to about 1,050 ppm. Between 15:45 and 16:10, the level was further decreased to 650 ppm because the sources of CO_2, students and teacher, moved to another room and were gone. From 16:20, ventilation was stopped for Period 5. But by 17:55 (end of monitoring), the level was changed to 1,100 ppm, because Doorway 2 was open. We calculated the ventilation rate in Room Y as 0.7 time/h in non-ventilation, 5.0 times/h in ventilation and 8.7 times/h in ventilation with Doorway-2 open (Table 2).

Table 2. Ventilation rate and room ventilation

	Ventilation rate (times/h)	
	Room X	Room Y
Observed in non-ventilation	1.0	0.7
Observed in ventilation	7.0	5.0 [8.7]
Estimated by the formulae	2.2	5.6

[ ], at Doorway 2.

Change in estimated levels

We figured changes in the presently observed and theoretically estimated CO_2 levels during the lec-

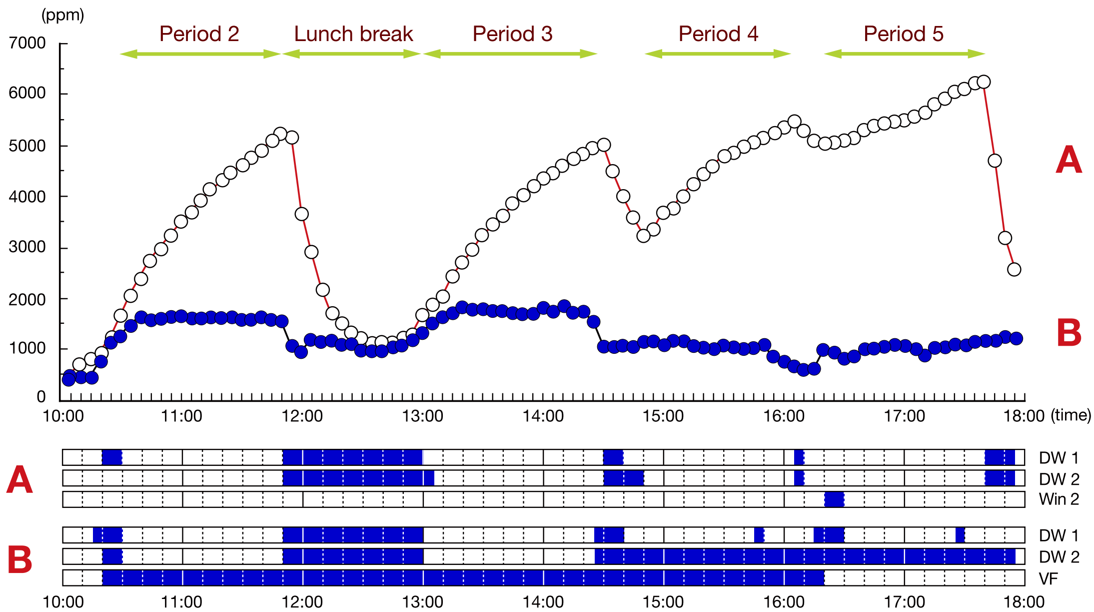

Fig. 3. Changes in CO_2 levels monitored in Room Y. **A:** not fan-ventilated. **B:** fan-ventilated. ■: fan-ventilated with doors open. DW, doorway; VF, ventilation fan; Win, window.

ture time over 90 min by room. The levels were based on the ventilation rates at 5-min intervals in ventilated and non-ventilated rooms (Fig. 4). The estimated value in non-ventilation at the end of the 90-min lecture was 6,075 ppm in Room Y and 2,307 ppm in Room X; while the observed value, 5,248 ppm in Room Y and 2,513 ppm in Room X. The estimated value in ventilated Room X fluctuated around 750 ppm 20 min after the lecture start, and was still 750 ppm 90 min later. The estimated value in ventilated Room Y fluctuated around 1,600 ppm 20 min after the lecture start, and was 1,621 ppm 90 min later.

Noise level

In non-ventilation, the noise level was 38 to 40 dB in Room X and 36 to 38 dB in Room Y. In ventilation, the noise level was 40 to 42 dB in Room X and 38 to 40 dB in Room Y.

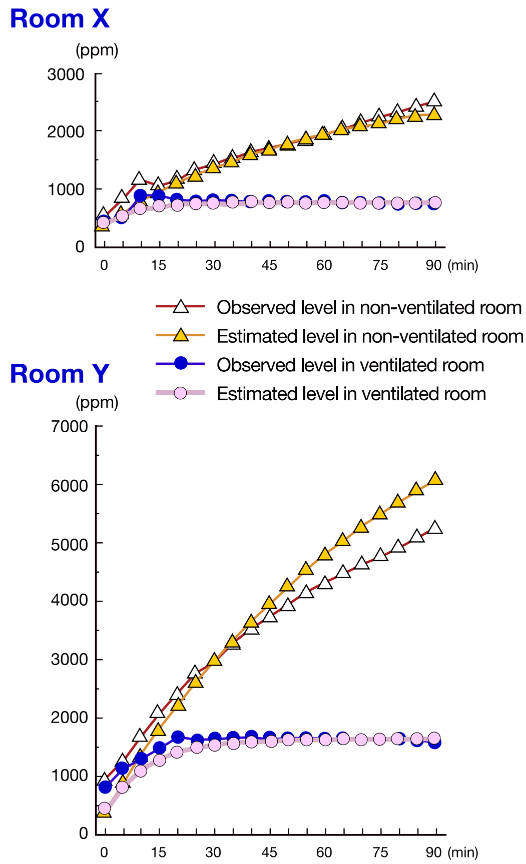

Fig. 4. Observed and estimated CO_2 levels in ventilated and non-ventilated Rooms X and Y. Room conditions for calculating estimated values were 0.022 m^3/h/person, 400 ppm as CO_2 of the indoor air at the monitoring start and 400 ppm as CO_2 of the air entering from outside.

Discussion

In 2002, the Ministry of Education, Culture, Sports, Science and Technology of Japan determined the standards for school indoor chemical substance density by revising the Standards for Environmental Hygiene in School (Ministry of Education, Culture, Sports, Science and Technology of Japan, 2002). The 2002 revision has recommended air quality control by checking the CO_2 density and ventilation rate twice a year. Most school classrooms in Japan have natural ventilation. The revision demands 0.15% (1,500 ppm) or less as the preferable level, and fixes standard ventilation times for classrooms. On the other hand in 1970, the Ministry of Health, Labour and Welfare of Japan established CO_2 standards for keeping contaminants (CO_2, formaldehydes and suspended particles) below standards, 0.1% (1000 ppm) by the Law for Maintenance of Sanitation in Buildings (Japanese Government, 1970): the Law stipulates evaluation of IA quality and degree of IA pollution.

The above standards are for the overall index of IA quality, not based on CO_2 effects on health, but based on increase of other contaminants estimated to be in parallel with the increase of CO_2 over 1,000 ppm. Indoor CO_2 is increased by students' exhaled air. When the indoor level is high, it is assumed that the room is not ventilated. As the result of non-ventilation, oxygen is decreased, suspended particles are increased, bacteria are increased and body odor gets severer for students to be annoyed about unpleasant smells (Takahashi, 1982; Ministry of Education, Culture, Sports, Science and Technology of Japan, 2004). On the other hand, 5,000 ppm has been determined as a permissible level by the Japan Association of Industrial Health and the American Conference of Governmental Industrial Hygienists (Araki, 1990; American Conference of Governmental Industrial Hygienists, 2007). The CO_2 level observed in the non-ventilated rooms far exceeded 1,500 ppm, the limit determined at the "Standards for School Environmental Sanitation". Sometimes the level exceeded 3,000 ppm in Room X and 6,000 ppm in Room Y.

The CO_2 level, an index of IA quality, is influenced by the ratio of air volume/person and ventilation rate. The ratio of air volume/person was higher in Room X than Room Y. Accordingly, the CO_2 level in non-ventilated Room X should have been lower than in non-ventilated Room Y. However, in the case of no ventilation, the level was kept above the standard in either room. We think that the highness was due to the sealed nature of the room during leture: the doorways were open only when the teacher and students entered for class or exit after class, as in the same way during the break. Moreover, room doors were opened during the break for coming-in and going-out of students, and open-door ventilation decreased the high CO_2 level. When doors were kept open in Room Y between 12:00 and 13:00, over 5,000 ppm CO_2 was decreased to below the standard. The effect of natural ventilation by opening room doors impacted.

As observed, when rooms were not ventilated, CO_2 attained a high density, and we fully realized the need of fan-ventilation. It is preferable to measure by every room to know actual conditions, but we cannot monitor many rooms with the present method. This is the reason we tried to estimate the measurements using the theoretical formulae. The estimated level as well as the observed level exceeded the standard of 1,500 ppm in non-ventilated rooms. The final CO_2 level differed according to the ratio of air volume/person; however, when the lecture room was sealed over 90 min, it was difficult to keep the level below standard regardless of air volume. In estimating and observing the levels, we started by setting the the initial indoor level as 400 and 450 ppm, respectively. But, both levels exceeded the standard within 90 min. Even if the CO_2 level was adjusted to below the standard during a break, in the case of no ventilation during a lecture, IA quality must be negatively affected and high-level air pollution would result. Accordingly, to keep IA clean, it is important to ventilate the lecture room during the lecture. The estimated levels were higher for Room Y than Room X both in ventilation and non-ventilation, presumably because the number of students in Room X was smaller than Room Y. The estimated levels higher than the observed in non-ventilated Room Y may be caused by ventilation taking place in Room Y by the openings and closings of doors.

The CO_2 level in ventilated rooms with doors closed was kept below the standard of 1,500 ppm in Room X, and slightly higher than the standard in Room Y. In considering these facts, ventilation of rooms can keep the CO_2 level below or near the standard, by which IA pollution would be reduced. The shift of estimated levels in ventilated rooms was similar to that of the observed, keeping below or slightly higher than the standard. In keeping IA clean in highly airtight university lecture rooms, it is important to ventilate the room during lecture by opening classroom doorways or by fan-ventilating. We observed that ventilation through opening doors had a large effect. However, opening doors introduces outside air directly indoors, and no temperature or amount of wind of the inflowing air can be controlled. We did not investigate the influence of opening doors on indoor thermal environment in the present study. We cannot expect that opening doors keep the environment within the comfortable range. Furthermore, when rooms are air-conditioned in summer and winter, ventilation by opening doors is not preferable also from the energy-saving aspect.

In contrast, ventilation by using ventilation fans can ensure a constant amount of ventilation. Accordingly, in the present study, we observed no rapid level change, but little change below the standard or near above. In the case of using ventilation fans, however, the influence on the indoor temperature and the amount of running noise will arouse concern. In the present study, the heat temperature setting for lecture rooms was fixed, and we could not confirm effects of ventilation on the thermal environment. By the way, the heat exchange type ventilation fan we used here can supply outside air by exchanging the temperature close to the room temperature, and so it can ventilate without losing thermal energy by heating and air conditioning (Japan Electrical Manufacturers' Association, 2007). The running noise when ventilation fans were operated exerted no influence on lectures, because the noise met the standard of 50 dB or less determined by the "Standards for School Environmental Sanitation".

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Received September 4, 2008; accepted March 31, 2009

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